# Modal frequencies of LIGO structures
# G070421-00-K

Justin Greenhalgh, Tim Hayler, Ian Wilmut

# Background

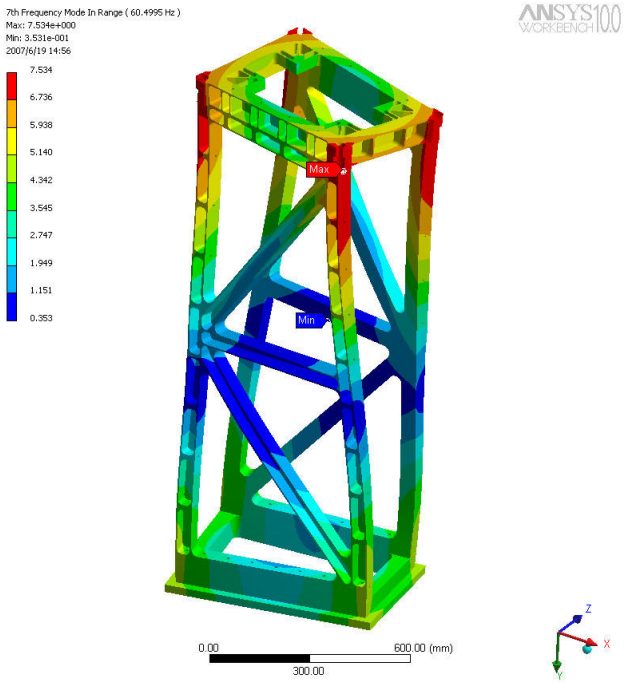
- During tests on LIGO structures, frequencies have been seen below the first predicted frequency as calculated by finite element analysis.
- Is this to do with the clamping, or that the structure is not fixed to something that is infinitely stiff ?

# Different approaches to validate peaks

- Tested unconstrained structures (suspended) so that clamping and fixing issues are redundant (T070147).
- Measured the movement at the base of the structure. Are the blocks fixed (T070135)?
- Done FEA on blocks (RAL test bed) that are not perfectly fixed to the floor (T070130).

# Tests on unconstrained structures

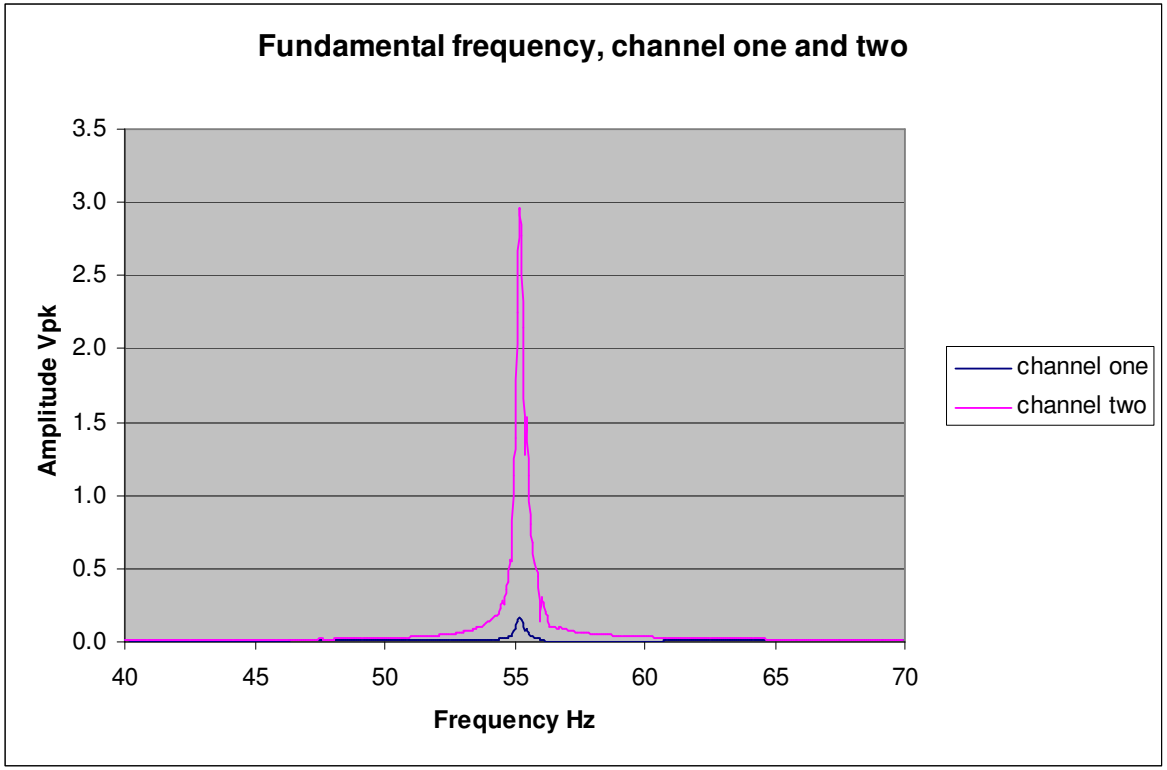
- Comparing the modal frequency results of a finite element analysis, with physical tests on suspended structure.




7th modal frequency from FEA

Structure suspended by green sling

Clearly defined first peak

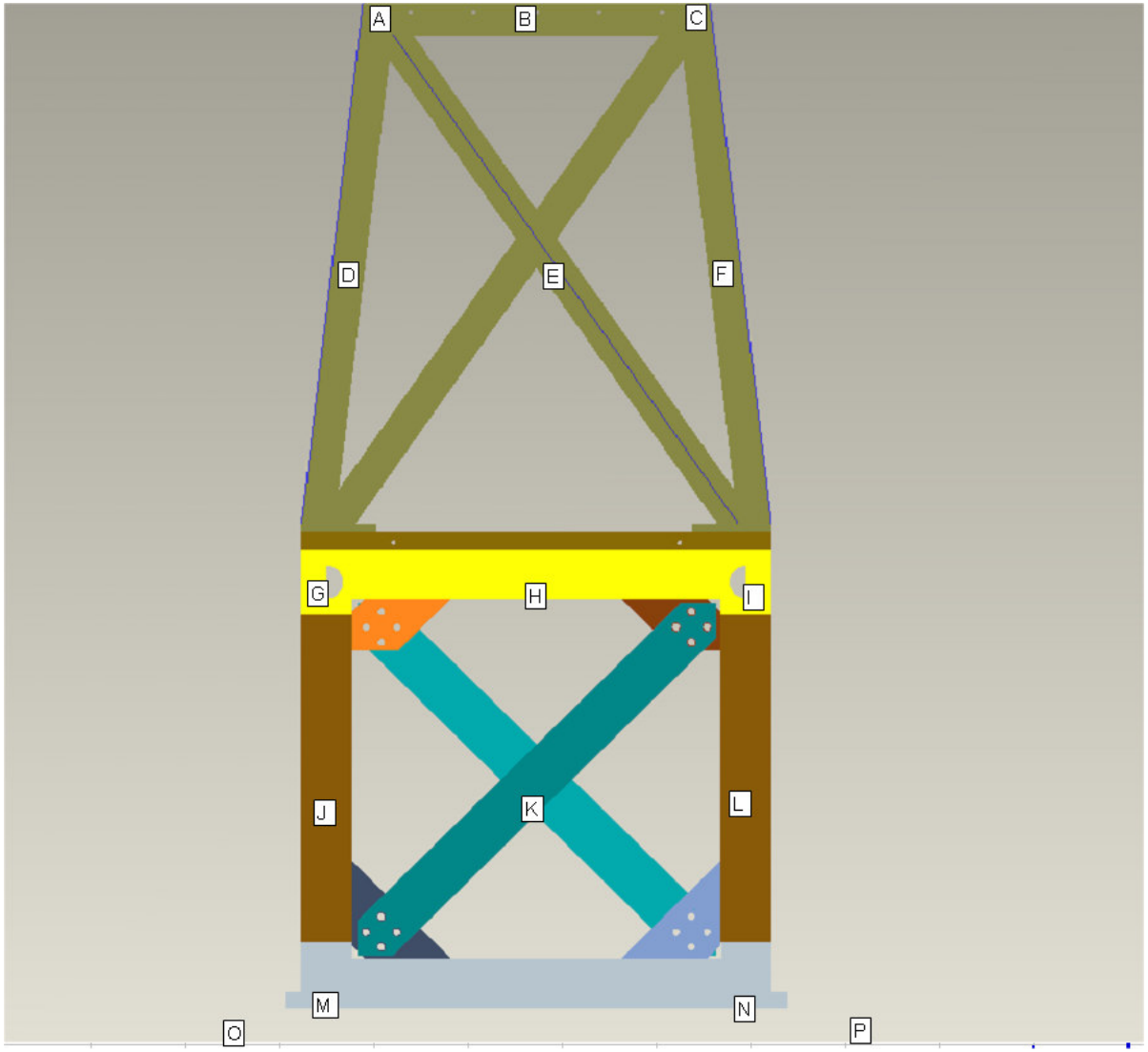



| Modal Frequency | FEA Hz | Measured Hz | Discrepancy % |
|---|---|---|---|
| 1st | 60 | 56 | 7 |

# Unconstrained structures - lessons

- It is possible to clearly identify modes from the FEA in a real test (single clear peak; mode shapes identifiable)
- Results are generally within ~10% of FEA
- (Exception in case of quad sleeve behaviour: explicable in terms of weld details)

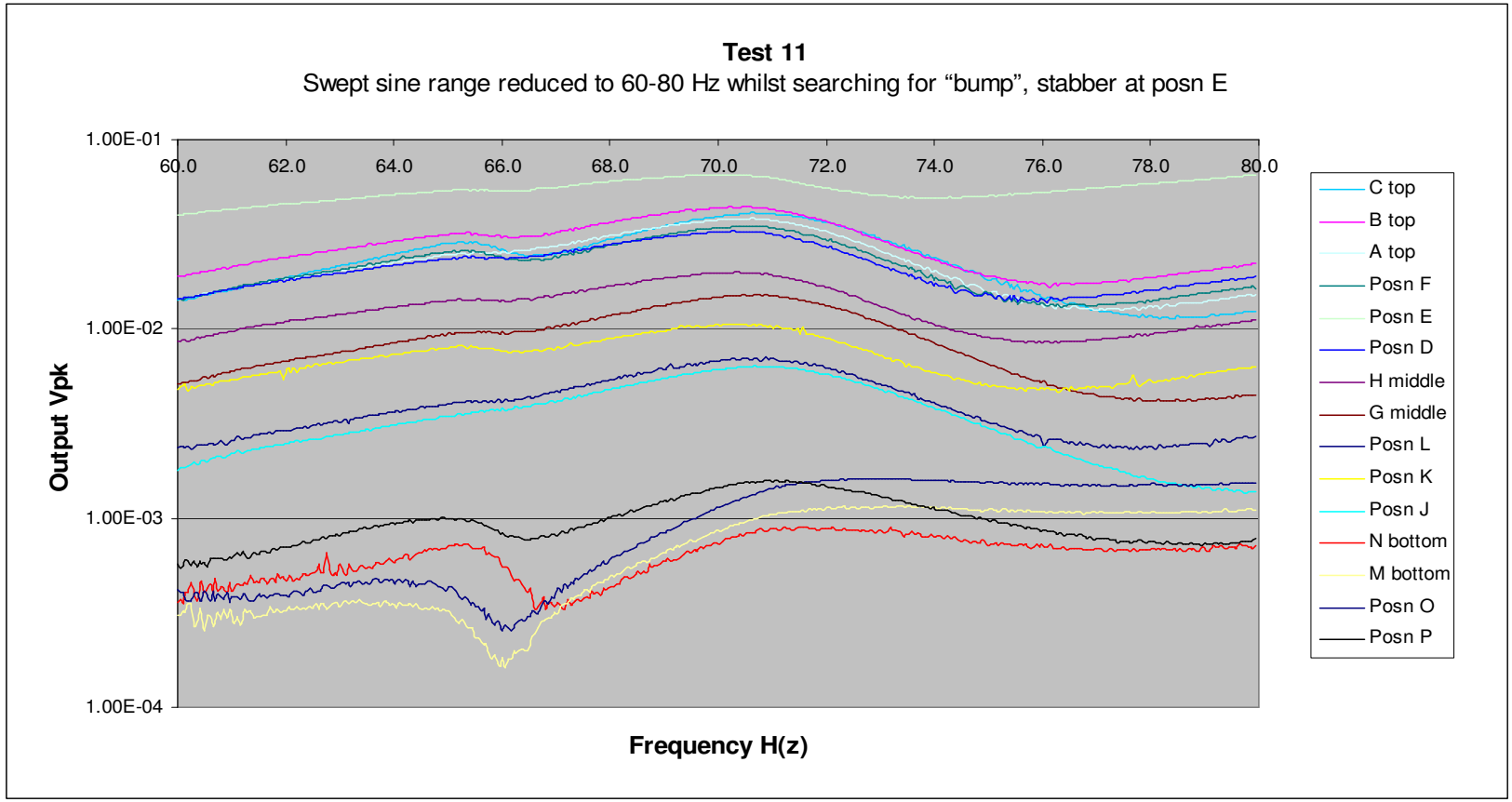
# Measuring movement at the base of the structure
## Accelerometer locations



# Modal testing of quad structure, longitudinal mode

## movement of the base relative to the structure

## real test 0.1, FEA 0.001



FEA movement of feet

- "Hard" model

| NODE | UX | UY | UZ | USUM |
|---|---|---|---|---|
| 174 | -0.70957E-04 | -0.83481E-04 | 0.73282E-03 | 0.74096E-03 |
| 330 | 0.61409E-01 | -0.27995E-01 | 0.16824E-01 | 0.69554E-01 |
| 565 | 0.13529 | -0.42635E-01 | 0.16829E-01 | 0.14284 |

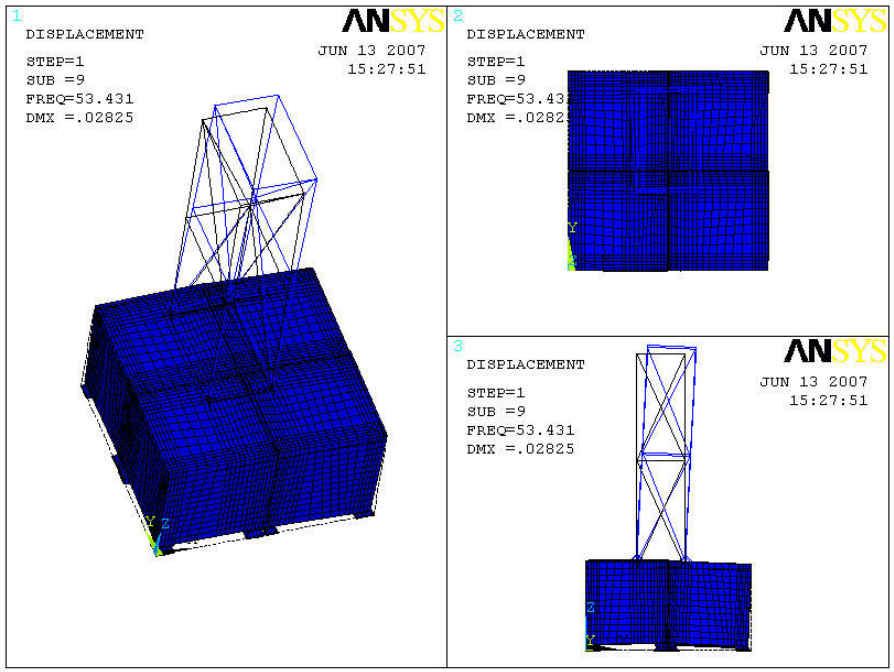
- "Soft" model (see below)

| NODE | UX | UY | UZ | USUM |
|---|---|---|---|---|
| 174 | -0.27769E-02 | 0.15187E-02 | 0.24795E-02 | 0.40207E-02 |
| 330 | 0.56097E-01 | -0.26329E-01 | 0.15835E-01 | 0.63959E-01 |
| 565 | 0.12681 | -0.40565E-01 | 0.15843E-01 | 0.13408 |

# Movement of feet - lessons

- FEA shows for rigidly fixed blocks the feet move ~0.001 times as far as the middle ring.
- Measurements show the feet move ~0.1 times as far as the middle ring
- FEA with imperfectly fixed blocks allows movement of similar order (see next slides).

# Effect of steel base blocks on frequency measurement T070130




- Fixed steel blocks compared to partially fixed steel blocks.
- Model with soft pads supporting the blocks.

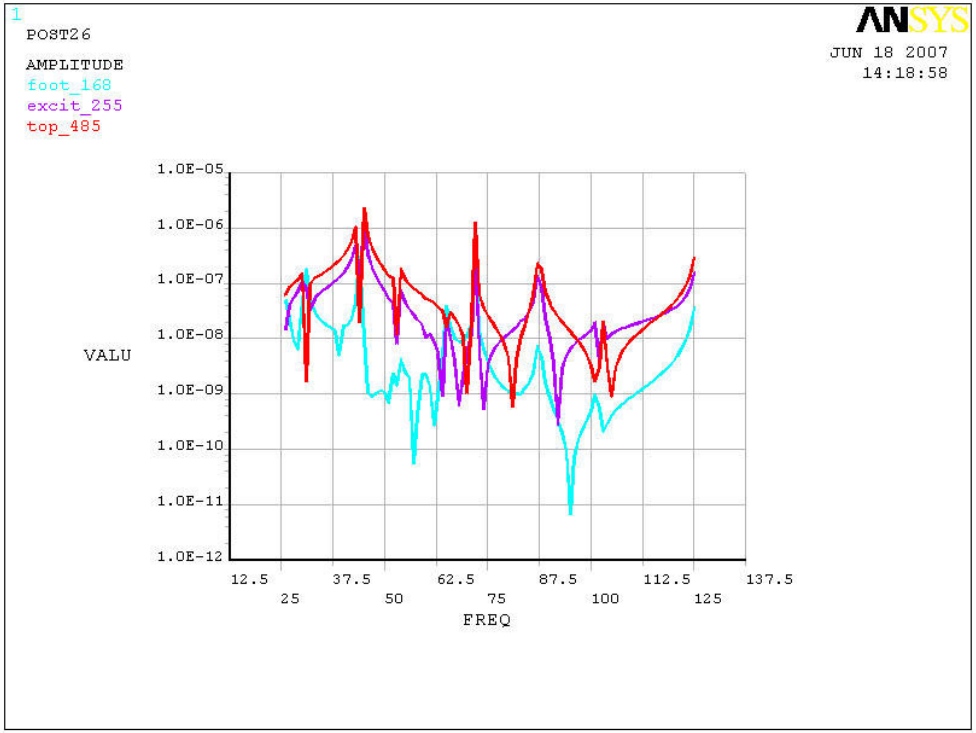
# Soft blocks - results

- See above for foot movement: better match to observations
- Also shows reduction in frequency of structure

| SET | TIME/FREQ |
|---|---|
| 1 | 89.324 |
| 2 | 138.41 |
| 3 | 195.35 |

| SET | TIME/FREQ | |
|---|---|---|
| 1 | 24.315 | Pads shear in X |
| 2 | 24.722 | Pads shear in Y |
| 3 | 30.718 | Blocks yaw en masse on pads about Z |
| 4 | 39.149 | two blocks yaw out of phase on pads |
| 5 | 43.789 | two blocks yaw on pads, structure cantilevers in X |
| 6 | 44.304 | two blocks yaw one way en masse; two the other way |
| 7 | 44.580 | similar to mode 5 |
| 8 | 51.809 | structure cantilevers in Y |
| 9 | 53.431 | two blocks lift (stretching pads in Z); structure cantilevers in X |
| 10 | 56.862 | two blocks roll (about Y) in opposition |
| 11 | 58.670 | blocks pitch and/or roll |
| 12 | 60.153 | blocks pitch and/or roll |
| 13 | 62.954 | blocks pitch, roll and yaw |
| 14 | 65.237 | blocks pitch, roll and yaw (see diagram below) |
| 15 | 72.035 | blocks roll about Y, structure cantilevers in X |
| 16 | 83.259 | two blocks yaw in opposition |
| 17 | 87.424 | blocks pitch; structure cantilevers in X |
| 18 | 101.58 | blocks roll; structure goes in torsion |
| 19 | 103.19 | blocks pitch, structure cantilever in Y |
| 20 | 125.84 | block roll, structure cantilevers in X |

# Harmonic response with soft pads




| | | |
|---|---|---|
| 1 | 24.315 | |
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| 4 | 39.149 | |
| 5 | 43.789 | * |
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| 7 | 44.580 | * |
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| 14 | 65.237 | |
| 15 | 72.035 | * |
| 16 | 83.259 | |
| 17 | 87.424 | * |
| 18 | 101.58 | |
| 19 | 103.19 | |
| 20 | 125.84 | * |

## Effect of base blocks – lessons

- There is at least one credible model of imperfectly supported blocks that gives movement of the feet such as we have seen
- This model also gives reduced natural frequencies, and “extra” peaks in the transmissibility curve at frequencies other than those associated with the structure itself.

# CONCLUSIONS

- Suspended method gives clear, comprehensible results

  7 out of 8 results were within 10% of FEA.
- From FE rigidly fixed blocks should work well, give accurate results.
- We have observed that the movement at the base of the structure is a factor of 0.1 less than the movement at the middle of the structure, predicted FEA says it should be 0.001, so blocks are moving more than they should.
- A simple FE model with blocks not perfectly constrained gives low level spurious peaks.